



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

Association of physical health multimorbidity with mortality in people with schizophrenia spectrum disorders

Using a novel semantic search system that captures physical diseases in electronic patient records

Kugathasan, Pirathiv; Wu, Honghan; Gaughran, Fiona; Nielsen, René Ernst; Pritchard, Megan; Dobson, Richard; Stewart, Robert; Stubbs, Brendon

Published in:
Schizophrenia Research

DOI (link to publication from Publisher):
[10.1016/j.schres.2019.10.061](https://doi.org/10.1016/j.schres.2019.10.061)

Creative Commons License
CC BY-NC-ND 4.0

Publication date:
2020

Document Version
Accepted author manuscript, peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Kugathasan, P., Wu, H., Gaughran, F., Nielsen, R. E., Pritchard, M., Dobson, R., Stewart, R., & Stubbs, B. (2020). Association of physical health multimorbidity with mortality in people with schizophrenia spectrum disorders: Using a novel semantic search system that captures physical diseases in electronic patient records. *Schizophrenia Research*, 216, 408-415. <https://doi.org/10.1016/j.schres.2019.10.061>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Text: 3858

Abstract: 249

of figures: 1

of tables: 3

Title:

Association of physical health multimorbidity with mortality in people with schizophrenia spectrum disorders: Using a novel semantic search system that captures physical diseases in electronic patient records

Running title:

Physical multimorbidity and mortality in schizophrenia

First author: Pirathiv Kugathasan ^{a,b}, MSc

Second author: Honghan Wu ^e, MSc, PhD

Third author: Fiona Gaughran ^{c,d}, MD, PhD

Fourth author: René Ernst Nielsen ^{a,b}, MD, PhD

Fifth author: Megan Pritchard ^{c,d}, MSc

Sixth author: Richard Dobson ^{f,g}, PhD

Seventh author: Robert Stewart ^{c,d}, MD

Eighth author: Brendon Stubbs ^{c,d}, MSc, PhD

Affiliations:

a: Psychiatry, Aalborg University Hospital, Aalborg, Denmark

b: Department of Clinical Medicine, Aalborg University, Aalborg, Denmark

c: King's College London, Institute of Psychiatry, Psychology and Neuroscience (IoPPN), De Crespigny Park, London, United Kingdom

d: South London and Maudsley NHS Foundation Trust, Denmark Hill, London, United Kingdom

e: Centre for Medical Informatics, Usher Institute of Population Health Sciences and Informatics, The University of Edinburgh, Scotland, United Kingdom

f: Department of Biostatistics and Health Informatics, Institute of Psychiatry, Psychology & Neuroscience, King's College London, London, UK

g: Health Data Research UK London, Institute of Health Informatics, University College London, London, United Kingdom

Corresponding author:

Pirathiv Kugathan

Aalborg University Hospital, Department of Psychiatry,

Mølleparkvej 10, 9000 Aalborg, Denmark

Telephone: +4528597494

Fax: +4597643626

E-mail: divkugathan@gmail.com

Accepted author manuscript

Abstract

Objective:

Single physical comorbidities have been associated with the premature mortality in people with schizophrenia-spectrum disorders (SSD). We investigated the association of physical multimorbidity (\geq two physical health conditions) with mortality in people with SSD.

Methods:

A retrospective cohort study between 2013 and 2017. All people with a diagnosis of SSD (ICD-10: F20-F29), who had contact with secondary mental healthcare within South London during 2011-2012 were included. A novel semantic search system captured conditions from electronic mental health records, and all-cause mortality were retrieved. Hazard ratios (HRs) and population attributable fractions (PAFs) were calculated for associations between physical multimorbidity and all-cause mortality.

Results:

Among the 9775 people with SSD (mean (SD) age, 45.9 (15.4); males, 59.3%), 6262 (64%) had physical multimorbidity, and 880 (9%) died during the 5-year follow-up. The top three physical multimorbidity combinations with highest mortality were cardiovascular-respiratory (HR: 2.23; 95% CI, 1.49-3.32), respiratory-skin (HR: 2.06; 95% CI, 1.31-3.24), and respiratory-digestive (HR: 1.88; 95% CI, 1.14-3.11), when adjusted for age, gender, and all other physical disease systems. Combinations of physical diseases with highest PAFs were cardiovascular-respiratory (PAF: 35.7%), neurologic-respiratory (PAF: 32.7%), as well as respiratory-skin (PAF: 29.8%).

Conclusions:

Approximately 2/3 of patients with SSD had physical multimorbidity and the risk of mortality in these patients was further increased compared to those with none or single physical conditions. These findings suggest that in order to reduce the physical health burden and subsequent mortality in

people with SSD, proactive coordinated prevention and management efforts are required and should extend beyond the current focus on single physical comorbidities.

Keywords: Schizophrenia, severe mental illness, mortality, somatic, comorbidity

Accepted author manuscript

1. Introduction

People with schizophrenia have life expectancies up to 20 years shorter than those in the general population (Chang et al., 2011; Walker, McGee, & Druss, 2015). The majority of early deaths (70%) are explained by physical health conditions, such as cardiovascular, respiratory and neoplastic diseases (Correll, Solmi, et al., 2017; Jayatilleke et al., 2017). Despite the established worse physical health morbidity in people with schizophrenia (Oud & Meyboom-de Jong, 2009; Razzano et al., 2015), most research to date has focused on single physical health conditions such as cardiovascular, respiratory disease, and diabetes (Schoepf et al., 2012; Vancampfort et al., 2016). However, in populations with poor physical health outcomes such as schizophrenia (DE Hert et al., 2011; Smith, Langan, McLean, Guthrie, & Mercer, 2013), people are often affected by two or more physical health conditions, termed physical health multimorbidity (Stubbs et al., 2016).

In the general population, the number of people with physical multimorbidity has increased in most countries around the world and is becoming one of the main challenges for health care systems (Dhalwani et al., 2016). A large-scale systematic review of more than 70 million people from the general population across 12 different countries suggested that the prevalence of multimorbidity was 13% in people aged 18 years and older, and a positive association between age and prevalence of multimorbidity (Violan et al., 2014). Multimorbidity is a concern, with data from the general population demonstrating that people affected are more likely to have functional decline (A. Ryan, Wallace, O'Hara, & Smith, 2015), worse quality of life (Fortin et al., 2004), increased risk of premature mortality (Di Angelantonio et al., 2015) and higher healthcare costs (Lehnert et al., 2011).

Whilst there have been concerted efforts to understand poor physical health in schizophrenia, little is known about the impact of physical health multimorbidity on mortality in these patients.

However, recent evidence indicates a higher risk of physical health multimorbidity compared to the general population (Gabilondo, Alonso-Moran, Nuño-Solinis, Orueta, & Iruin, 2017; Stubbs et al., 2016), and a recent large multinational study in low- and middle-income countries, concluded that

psychosis was associated with an increased odds ratio of 4.1 for physical multimorbidity, compared to controls (Stubbs et al., 2016). Stubbs et al. reported that psychosis patients had high levels of asthma combined with diabetes, angina pectoris or tuberculosis, and arthritis combined with angina pectoris, and hearing problems combined with visual impairment or edentulism (Stubbs et al., 2016). The study by Gabilondo et al. showed that physical disease clusters of neuropsychiatric conditions (Parkinson, dyspepsia, cerebrovascular disease) as well as cardiovascular and respiratory disease clusters were most common (Gabilondo et al., 2017). Even though such combinations show that physical morbidities co-occur frequently in patients with SSD, no studies have to date investigated the impact of such combinations to mortality, which is necessary in order to understand and possibly reduce the premature mortality in patients with SSD.

Clearly, an improved evidence base is important to identify at risk groups, develop interventions, and address the premature mortality. Since SSD is a heterogeneous condition (Os & Kapur, 2009), which is associated with premature mortality (Walker et al., 2015) and greatly increased single physical health comorbidities, we aimed to investigate the prevalence of physical health multimorbidity in people with SSD. Secondly, we assessed which physical health conditions and clusters (i.e. combinations of physical disease systems) are likely to be associated with increased mortality rates in patients with SSD using data from a large electronic health record (EHR) platform.

2. Methods

2.1 Study design

A retrospective cohort study using data from electronic mental health records linked to national mortality surveillance with a five-year follow-up period.

2.2 Study period

Cohort selection and characterisation used data from 2011-2012. Follow-up ran from January 1, 2013 to December 31, 2017.

2.3 Data source

Data were derived from the Clinical Record Interactive Search (CRIS); a case register system that contains de-identified electronic health record (EHR) data from the South London and Maudsley (SLaM) National Health Service Foundation Trust. SLaM is one of the largest mental healthcare services in Europe, providing comprehensive mental health care to a catchment of approximately 1.3 million residents in south London (Croydon, Lambeth, Lewisham, and Southwark). EHRs have been used across all SLaM services since 2006, and CRIS was established with funding from the National Institute of Health Research (NIHR) as a 'live' resource, commencing with imported legacy data in 2008 and accumulating information on the full SLaM caseload since that time (Perera et al., 2016). CRIS data are accessed and used within a robust governance model, and CRIS has received research ethics approval as a data resource for secondary analysis (Oxford REC C, reference 18/SC/0372).

2.4 Study population

The cohort included all individuals aged 18 years or older with a diagnosis of SSD (ICD-10: F20-F29) and had at least one face to face contact with SLaM during the period between 1st January 2011 and 31st December 2012, and who were alive on 1st January 2013 (set up in this way to allow all cases to have at least 5 year follow-up). In recognition of the heterogeneous nature of schizophrenia, we included the spectrum of schizophrenia (SSD) as in accordance with previous research papers (Chang et al., 2010; Stubbs, Mueller, et al., 2018). We used primary and secondary diagnoses of F20-29 within the structured ICD-10 codes that were recorded routinely in the source EHR. Physical health conditions were ascertained, using natural language processing (NLP) as described below, from data reported in CRIS at any time before index date (1st January 2013). We defined physical health multimorbidity as combination of two- or more physical health disease categories within one person at any given time before index date (Stubbs et al., 2016; Violan et al., 2014). These physical diseases were then grouped into the letter-based chapters from ICD-10 version 16 (World Health Organisation, 2016).

2.5 Semantic computing and learning system to capture physical health comorbidities on electronic patient records

To identify patients' physical health conditions from these clinical notes, we used SemEHR – an open source toolkit that integrates text mining and semantic computing for identifying mentions of UMLS (Unified Medical Language System) concepts from clinical documents (Wu et al., 2018). To identify mentions of a broad range of physical diseases (ICD-10; A00-N99), we mapped each top level ICD code (3-character code, e.g. A00) to a corresponding UMLS concept CUI (e.g. C0008354) using the mappings available at BioPortal (<http://sparql.bioontology.org/>) by querying its SPARQL Endpoint. The first benefit of using UMLS concepts instead of ICD-10 terms is that UMLS provides extensive synonyms for each concept, which helps identifying as many variants of disease mentions as possible. The second benefit comes from the comprehensive concept relations provided by UMLS, which helps the disambiguation in NLP and the identification of more disease subtypes.

To optimise performance for identifying physical condition mentions, we used SemEHR's continuous learning functionality to iteratively improve its text-mining model on these conditions. Briefly, each iteration includes sampling (random selection of a fixed number of mentions for each top-level condition), validation (manual assessment of samples on a specific browser-based user interface) and learning (validation results learnt by the system to improve the model). Based on previous studies on SLAM data, the recall (sensitivity) of SemEHR is generally very good (96-98%) for physical conditions at document level (Wu et al., 2018). The accuracy achieved for affirmed, recent and patient-suffered conditions was $83\% \pm 0.13$ (precision) - over 50 codes (2,960 instances) - at document level. The most comparable processing resource is CRIS-CODE (Jackson et al., 2017), which validated 46 mental health symptoms on CRIS with 85% precision. The SemEHR classification were found to have continued poor performance despite training for some physical disease systems, namely; bacterial infection (chapter A), neoplasm (chapter C), diseases of the blood and blood-forming organs (chapter D), and eye and ear (chapter H). These were therefore not included in the

multimorbidity algorithm used for analyses described here, which instead ascertained viral infection (chapter B, e.g. HIV, mycoses, hepatitis.), endocrine (chapter E, e.g. diabetes mellitus, cystic fibrosis, obesity), neurologic (chapter G, e.g. Parkinson disease, epilepsy, Huntington disease), cardiovascular (chapter I, e.g. stroke, heart failure, myocardial infarction), respiratory (chapter J, e.g. asthma, bronchitis, chronic obstructive pulmonary disease), digestive (chapter K, e.g. liver diseases, gastric ulcer, irritable bowel syndrome), skin (chapter L, e.g. psoriasis, eczema, dermatitis), musculoskeletal (chapter M, e.g. systemic lupus, arthrosis, dorsopathies) and urogenital (chapter N, e.g. renal failure, endometriosis, diseases of genital (male/female) organs) systems. The precision at chapter level after removing poor-performing chapters is $86\% \pm 0.11$. The source of validation data was generated in the study by two annotators (P.K. and R.S.) via 16 rounds of iterations. The precision at chapter-level was estimated by manual assessments on sampled documents (80 documents per chapter of the last rounds). It needs to be noted that reported performances in this section are not for asserting conditions at patient-level, i.e. decide whether a patient had a physical condition or not. Instead, they were evaluated for the ability to identify whether a sequence of words is a contextualised condition mention (phenotype identification task). To translate phenotype task results to patient-level condition asserting, our previous study (Wu et al., 2018) on SLAM CRIS showed that a model with 85–87% precision at phenotype identification tasks on free-text can achieve 93–99% F-measure at patient-level for Hepatitis C and HIV diseases. The SemEHR has also been recently used and validated against other machine learning tools on Radiology Reports in Scotland (Gorinski et al., 2019).

2.6 Outcomes and measures

The index date for characterisation of the cohort and commencement of follow-up was defined as 1st January 2013, and the sample was thus restricted to all individuals who were alive at this time. The follow-up began on 1st January 2013 and ended on 31st December 2017, or at the day of death, whichever came first. The date of death of each deceased patient was obtained from CRIS, using a

linkage between SLaM's EHR and the national mortality spine updated on at least a monthly basis and complete for the entirety of the follow-up period.

2.7 Covariates

We obtained sociodemographic data for the cohort in relation to the index date, including age (18-39, 40-59, >60), sex (male, female), ethnicity (White, Black/Caribbean, others/mixed/unknown), and marital status (married/cohabiting, divorced, single), using structured EHR data accessed via CRIS. In the United Kingdom, mental health services have completed the Health of the Nation Outcome Scales (HONOS) among all patients. The HONOS is also widely used in Australia and New Zealand and is a validated measure with robust psychometric properties to routinely assess outcomes in mental health service users (Bebbington, Brugha, Hill, Marsden, & Window, 1999; Pirkis et al., 2005). We used five subscales from the routine HoNOS within the EHR, and these were obtained based on their specific relevance for this particular patient group, including agitated/aggressive behaviour, self-injury, substance use, cognitive problems and depression scores. Each score was divided into three categories of not present (HoNOS subscale score 0), minimal or questionable (score 1) or significant (scores 2-4); these were based on the closest HoNOS recorded within a year prior to, or up to 3 months after index date (1st January 2013).

The address recorded as current or most recent at the index date was linked to the Index of Multiple Deprivation (IMD) score for that neighbourhood, derived from 2011 national Census data, and providing a measure of neighbourhood-level socioeconomic status (Department for Communities and Local Government, 2015).

2.8 Statistical analysis

Descriptive statistics for all variables were calculated as frequencies and percentages. The baseline characteristics included information on age (bands), sex, ethnicity, marital status, HoNOS, and deprivation score (divided in quantiles). In addition, the numbers of physical disease systems affected were grouped into categories from 0-6.

First, prevalence (percentage) of physical multimorbidity was calculated by combining two disease systems affected. The prevalence estimates of physical multimorbidity were demonstrated by ranking the most frequency occurring individual disease systems, and were expressed into categories of $\geq 10\%$, 5-9%, and $< 5\%$.

Second, a Cox proportional hazards regression analysis was performed to study the relationship between physical multimorbidity and mortality for all possible disease combinations compared to those people with schizophrenia who had no recorded physical diseases. We adjusted for age at index and sex in the first adjusted model and then further adjusted for all other disease systems to account for an increased mortality driven by other disease systems than those combinations investigated. We calculated crude and adjusted HRs and their 95% CIs by using patients with SSD who had no recorded physical diseases as reference..

Finally, the population attributable fraction (PAF) for mortality was calculated to assess the effect of different physical disease combinations on mortality. The PAF (expressed as a percentage) is a measure of proportion of deaths that might hypothetically be prevented if the disease combinations were not present. PAF calculations were carried out using STATA package “punafcc” for the adjusted cox regression model according to methods previously described (Spiegelman, Hertzmark, & Wand, 2007). Statistical significance were defined as $p < 0.05$. All analyses were conducted using STATA version 14.

3. Results

A total of 9775 people with SSD were assembled for the analysed cohort, with a mean (SD) age of 45.9 (15.4) on the index date; 59.3% were males. Most of the sample were single (74.6%), and of black African/Caribbean (44.4%) or white (40.8%) ethnicity. The first column of Table 1 describes the characteristics of the total cohort.

-Insert Table 1 here-

3.1 Prevalence of physical disease in patients with SSD

Among the 9775 people with SSD, 1798 (18.4%) did not have any recorded physical disease systems affected, 1715 (17.5%) had one disease system affected, 1639 (16.8%) had two disease systems affected, and 1403 (14.4%) had three disease systems affected. The prevalence of people with physical multimorbidity was 6,262 (64.1%). The most common disease systems affected were neurological (49.7%), endocrine (42.4%), and respiratory (36.9%), see table 1. Figure 1 shows that the most frequently observed two-way disease combinations were neurologic-endocrine system (27.9%), followed by neurologic-respiratory system (25.2%) and neurologic-viral infection (24.9%).

-Insert Figure 1 here-

3.2 The association between baseline variables and mortality

A total of 880 (9.0%) people with SSD died during the 5-year follow up period. As described in table 1, in models including age and sex, the demographic variables that remained associated with increased mortality were increased age and male sex. Black compared to white ethnic group was associated with significant lower mortality. Of clinical characteristics, aggressive behaviour, self-injury and substance abuse were all associated with increased mortality. Compared to people without physical disease, all specific physical disease systems had significantly increased mortality. People with SSD, who had two physical diseases or more, had increased mortality, compared to those without physical diseases. When comparing individuals with physical multimorbidity versus those with ≤ 2 physical disease systems, we observed a significant increased mortality in the multimorbidity group (HR: 1.23; 95% CI, 1.07-1.43).

3.3 The association between physical health multimorbidity and mortality

Table 2 displays Cox regression analyses of the associations between two-disease combinations and mortality. Among people with physical multimorbidity, most of the two-way combinations were associated with significantly increased mortality. Compared with the reference group, the highest age- and sex adjusted HR for mortality was 2.07 (95% CI, 1.42-3.02) for people with digestive-urogenital diseases, 2.05 (95% CI, 1.45-2.88) for people with skin-urogenital diseases and 2.00 (95%

CI, 1.48-2.72) for people with respiratory-urogenital diseases. However, these specific combinations fell below statistical significance levels after further adjustment for other physical disease groups.

In the final adjusted model, only respiratory diseases combined with other disease systems remained significantly increased, with the highest mortality observed in cardiovascular-respiratory diseases (HR: 2.23; 95% CI, 1.49-3.32), followed by respiratory-skin (HR: 2.06; 95% CI, 1.31-3.24) and respiratory-digestive (HR: 1.88; 95% CI, 1.14-3.11). Having respiratory disease alone compared to those without any physical disease did not significantly increase mortality, but only when respiratory diseases were combined with other disease systems, we observed an increased mortality. The only single physical disease system that alone increased mortality was cardiovascular disease (HR: 1.97; 95% CI, 1.24-3.12), all others were insignificant, but the number of people who only had one disease systems affected were generally low.

-Insert Table 2 here-

3.4 Population attributable fractions of physical multimorbidity and mortality

The top five highest PAFs are shown in table 3. The cardiovascular-respiratory disease combination had the highest PAF of 35.7%, followed by neurologic-respiratory (PAF: 32.7%) and respiratory-skin (PAF: 29.8%).

-Insert Table 3 here-

4. Discussion

To the best of our knowledge, the current study is the first to investigate the association between physical multimorbidity and mortality in people with SSD. In this retrospective cohort study of 9,775 patients with SSD with a mean age of 46 years, we found that 64% had physical health multimorbidity. The most frequently observed disease combinations were neurologic-endocrine system (28%), neurologic-respiratory system (25%), and viral infection-neurologic system (25%). Cardiovascular disease combined with respiratory disease had highest mortality rate (HR: 2.23; 95% CI, 1.49-3.32) and at the same time showed highest PAF (35.7%), but also respiratory-neurologic (HR:

1.84; 95% CI, 1.35-2.52, PAF: 32.7%) and respiratory-skin (HR: 2.06; 95% CI, 1.31-3.24, PAF: 29.8%) were associated with excess mortality in people with SSD, compared to those without physical diseases.

Previous studies have reported increased risk of physical health multimorbidity in people with schizophrenia (Gabilondo et al., 2017; Stubbs et al., 2016). Our study is the first to include a large scale of physical diseases to explore the most frequently co-occurring physical disease systems in people with SSD. Previous findings have reported prevalence of physical multimorbidity of 29% (Gabilondo et al., 2017), 33% (Smith et al., 2013), 36% (Stubbs et al., 2016) and 39% (Correll, Ng-Mak, et al., 2017), in people with schizophrenia. Our prevalence rate of 64% with physical multimorbidity is higher than the prevalence rates observed in those studies, but given the differences in the inclusion criteria of physical diseases, it is not surprising that we found higher prevalence rates than those who only included specific physical diseases. The most common physical disease systems affected were neurologic, endocrine, and respiratory systems, although we cannot determine whether they are higher than expected due to the lack of a non-schizophrenia comparison group. However, neurologic diseases, especially epilepsy and migraine, have been previously linked to psychosis (Clancy, Clarke, Connor, Cannon, & Cotter, 2014). It has also previously been suggested that there might be similar genetic pathways between schizophrenia and neurologic conditions (Ferentinos & Dikeos, 2012). On the other hand, the increased prevalence of neurologic diseases observed in this population may also be explained by the side effects of first-generation antipsychotics, as many patients will experience extrapyramidal side effects (Miller et al., 2008). Endocrine diseases, including diabetes mellitus, obesity, and thyroid diseases are increased in patients with schizophrenia compared to the general population (Pillinger, Beck, Stubbs, & Howes, 2017; M. C. M. Ryan, Collins, & Thakore, 2003). This can partly be explained by unhealthy lifestyle risk behaviors (Vancampfort, Firth, et al., 2017), side effects from second-generation antipsychotics (Manu et al., 2015), as well as common genetic pathways between psychosis and metabolic disorders (Tandon, Keshavan, & Nasrallah, 2008). Most studies regarding physical multimorbidity in

the general population have focused on populations above the age of 60 years (Guisado-Clavero et al., 2018; Schäfer et al., 2010), making comparison between people with SSD and the general population much more challenging. However, high smoking rates, substance abuse, unhealthy dietary behaviours (Firth et al., 2018) as well as less physical activity (Stubbs, Vancampfort, et al., 2018) are important risk factors for physical multimorbidity in people with psychosis (Laursen et al., 2013; Ringen, Engh, Birkenaes, Dieset, & Andreassen, 2014; Vancampfort, Koyanagi, et al., 2017), and might also explain the increased prevalence of respiratory diseases. Future studies are needed to explore the main contributing factors that predict development of co-occurring physical diseases, as well as the effectiveness of early screening and intervention to reduce the likelihood of developing physical multimorbidity in people with SSD.

Our data clearly demonstrate that physical health multimorbidity is an important contributor to the excess mortality in people with SSD. Previous research in people with physical multimorbidity from the general population has demonstrated that the number of physical comorbidities are associated with increased mortality (Ferrer, Formiga, Sanz, Almeda, & Padrós, 2017). No other studies have investigated the PAF of physical diseases for mortality in people with schizophrenia, so comparisons are difficult, since previous studies have only focused on single comorbid diseases. In the current study, we showed that a single disease was not associated with an increased mortality (however it reached almost significance), but patients who had two or more physical diseases were associated with increased mortality. The risk of premature mortality in patients suffering from two-way disease combinations was further increased compared to those with none or single physical disease condition. This could indicate that the excess mortality observed in people with SSD is not driven by the presence of a single disease system but is associated with the presence of physical multimorbidity. The finding that respiratory, cardiovascular and neurologic disease combinations had the highest impact on mortality adds impetus to further study the underlying aetiology of the impact of these disease combinations on the excess mortality in people with SSD. Patients with physical multimorbidity may find that one physical disorder creates difficulty in the management of

another, which could affect compliance with medical treatment for their health condition, and thereby possibly explain some of the increased mortality. Smoking is an important confounder that affects multiple organ systems, but especially cardiovascular and respiratory systems (Yanbaeva, Dentener, Creutzberg, Wesseling, & Wouters, 2007), and we cannot quantify the possible effect of this or other confounders on the excess mortality observed. Whether these disease systems affected are the same relative increase in mortality in patients with SSD as compared to the general population remain unanswered, as we did not have any data on a psychiatric healthy population. However, more research is required to unravel the findings of the current study, which should be given high priority because of this excess mortality.

4.1 Limitations

Whilst our data provide novel insights into this neglected area, some limitations need to be addressed. First, we were only able to follow patients for 5 years, and there are potentially large differences in short-term and long-term outcome for different physical disease systems. Second, we did not have information regarding the specific time-point of the recorded physical disease, as some might have had the diagnosis for several years, while others might just have received the diagnosis, which may have led to differences in the estimated mortality rates. Third, we did not assess the severity of the physical condition, and we are aware that within each disease system investigated there are large variations between physical conditions in terms of importance for mortality. Fourth, we had incomplete disorder systems captured by the SemEHR, since we did not develop sufficient accuracy for cancer (mainly due to feared entity) as well as bacterial infections (because some vaccinations were captured here). Fifth, the NLP and its performance needs to be further developed in terms of accuracy, but any inaccuracy would reduce rather than exaggerate associations with mortality. Nevertheless, our findings are showing good predictive validity and a novel multimorbidity measure that could be routinely applied to EHRs for health monitoring and risk stratification. Sixth, there is an issue as to whether physical health conditions are recorded at all in a mental health record, and it might even be possible that physical conditions are more likely to be recorded in

people with more severe mental disorders or risk states, but we were unable to adjust for this in the current data. On the other hand, when a physical health disorder is recorded, it means that it is recognized, so there could also be an obscuring effect of recognition and relatively better outcomes. The increased risk of suicide mortality in these patients challenges the findings observed in the current study, as many patients die early without having the chance to develop somatic diseases (competing risk). This is often considered as a major limitation in observational studies. It is also a major limitation that the current data did not include information on important confounders, such as smoking and alcohol consumption as well as levels of physical activity and intake of healthy diet, which are important variables in morbidity and mortality outcomes. For example, the finding that respiratory system is a strong contributor for morbidity and mortality in patients with SSD could be confounded by the excessive rates of smokers in patients with SSD, and we would have expected to reduce some of the respiratory mortality if we were able to include smoking as a variable in our regression model. On the other hand, smoking cessation is very difficult to implement in patients with SSD, and some patients even use smoking as self-medication to handle negative and cognitive symptoms (Winterer, 2010), which again challenges the use of such adjustment in our analysis. Lastly, when considering the generalisability of the cohort, we included people with SSD known to mental healthcare, so it is not possible to generalize these findings to those people with undiagnosed disorders or those treated in primary care alone, which might include people with better prognosis of mental disorders.

5. Conclusion

In a large representative sample, we identified that approximately two thirds of people with schizophrenia had physical multimorbidity. The current data is the first to address physical multimorbidity and its association to mortality in people with SSD, and suggest that cardiovascular-respiratory, neurologic-respiratory, and respiratory-skin disease combinations had the highest impact on mortality rates. Our data indicate that current treatment models for improving physical

health and reducing premature mortality in SSD need to acquire a more coordinated approach and move beyond the consideration of single disease systems.

Accepted author manuscript

References

- Bebbington, P., Brugha, T., Hill, T., Marsden, L., & Window, S. (1999). Validation of the Health of the Nation Outcome Scales. *British Journal of Psychiatry*, 174(5), 389–394. <https://doi.org/DOI:10.1192/bjp.174.5.389>
- Chang, C. K., Hayes, R. D., Broadbent, M., Fernandes, A. C., Lee, W., Hotopf, M., & Stewart, R. (2010). All-cause mortality among people with serious mental illness (SMI), substance use disorders, and depressive disorders in southeast London: A cohort study. *BMC Psychiatry*. <https://doi.org/10.1186/1471-244X-10-77>
- Chang, C. K., Hayes, R. D., Perera, G., Broadbent, M. T. M., Fernandes, A. C., Lee, W. E., ... Stewart, R. (2011). Life expectancy at birth for people with serious mental illness and other major disorders from a secondary mental health care case register in London. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0019590>
- Clancy, M. J., Clarke, M. C., Connor, D. J., Cannon, M., & Cotter, D. R. (2014). The prevalence of psychosis in epilepsy; a systematic review and meta-analysis. *BMC Psychiatry*. <https://doi.org/10.1186/1471-244X-14-75>
- Correll, C. U., Ng-Mak, D. S., Stafkey-Mailey, D., Farrelly, E., Rajagopalan, K., & Loebel, A. (2017). Cardiometabolic comorbidities, readmission, and costs in schizophrenia and bipolar disorder: A real-world analysis. *Annals of General Psychiatry*, 16(1), 9. <https://doi.org/10.1186/s12991-017-0133-7>
- Correll, C. U., Solmi, M., Veronese, N., Bortolato, B., Rosson, S., Santonastaso, P., ... Stubbs, B. (2017). Prevalence, incidence and mortality from cardiovascular disease in patients with pooled and specific severe mental illness: a large-scale meta-analysis of 3,211,768 patients and 113,383,368 controls. *World Psychiatry*, 16(2), 163–180. <https://doi.org/10.1002/wps.20420>
- DE Hert, M., Correll, C. U., Bobes, J., Cetkovich-Bakmas, M., Cohen, D., Asai, I., ... Leucht, S. (2011). Physical illness in patients with severe mental disorders. I. Prevalence, impact of medications and disparities in health care. *World Psychiatry : Official Journal of the World Psychiatric Association (WPA)*, 10(1), 52–77. <https://doi.org/10.1002/j.2051-5545.2011.tb00014.x>
- Department for Communities and Local Government. (2015). English indices of multiple deprivation 2015.
- Dhalwani, N. N., O'Donovan, G., Zaccardi, F., Hamer, M., Yates, T., Davies, M., & Khunti, K. (2016). Long terms trends of multimorbidity and association with physical activity in older English population. *International Journal of Behavioral Nutrition and Physical Activity*, 13(1). <https://doi.org/10.1186/s12966-016-0330-9>
- Di Angelantonio, E., Kaptoge, S., Wormser, D., Willeit, P., Butterworth, A. S., Bansal, N., ... Danesh, J. (2015). Association of cardiometabolic multimorbidity with mortality. *JAMA - Journal of the American Medical Association*, 314(1), 52–60. <https://doi.org/10.1001/jama.2015.7008>
- Ferentinos, P., & Dikeos, D. (2012). Genetic correlates of medical comorbidity associated with schizophrenia and treatment with antipsychotics. *Current Opinion in Psychiatry*. <https://doi.org/10.1097/YCO.0b013e3283568537>
- Ferrer, A., Formiga, F., Sanz, H., Almeda, J., & Padrós, G. (2017). Multimorbidity as specific disease combinations, an important predictor factor for mortality in octogenarians: The Octabaix study. *Clinical Interventions in Aging*, 12, 223–231. <https://doi.org/10.2147/CIA.S123173>
- Firth, J., Stubbs, B., Teasdale, S. B., Ward, P. B., Veronese, N., Shivappa, N., ... Sarris, J. (2018). Diet as a hot topic in psychiatry: a population-scale study of nutritional intake and inflammatory potential in severe mental illness. *World Psychiatry : Official Journal of the World Psychiatric Association (WPA)*, 17(3), 365–367. <https://doi.org/10.1002/wps.20571>
- Fortin, M., Lapointe, L., Hudon, C., Vanasse, A., Ntetu, A. L., & Maltais, D. (2004). Multimorbidity and

- quality of life in primary care: A systematic review. *Health and Quality of Life Outcomes*.
<https://doi.org/10.1186/1477-7525-2-51>
- Gabilondo, A., Alonso-Moran, E., Nuño-Solinis, R., Orueta, J. F., & Iruin, A. (2017). Comorbidities with chronic physical conditions and gender profiles of illness in schizophrenia. Results from PREST, a new health dataset. *Journal of Psychosomatic Research*, 93, 102–109.
<https://doi.org/10.1016/j.jpsychores.2016.12.011>
- Gorinski, P. J., Wu, H., Grover, C., Tobin, R., Talbot, C., Whalley, H., ... Alex, B. (2019). Named Entity Recognition for Electronic Health Records: A Comparison of Rule-based and Machine Learning Approaches, (2008), 12–16.
- Guisado-Clavero, M., Roso-Llorach, A., López-Jimenez, T., Pons-Vigués, M., Foguet-Boreu, Q., Muñoz, M. A., & Violán, C. (2018). Multimorbidity patterns in the elderly: A prospective cohort study with cluster analysis. *BMC Geriatrics*, 18(1), 16. <https://doi.org/10.1186/s12877-018-0705-7>
- Jackson, R. G., Patel, R., Jayatilleke, N., Kolliakou, A., Ball, M., Gorrell, G., ... Stewart, R. (2017). Natural language processing to extract symptoms of severe mental illness from clinical text: The Clinical Record Interactive Search Comprehensive Data Extraction (CRIS-CODE) project. *BMJ Open*. <https://doi.org/10.1136/bmjopen-2016-012012>
- Jayatilleke, N., Hayes, R. D., Dutta, R., Shetty, H., Hotopf, M., Chang, C. K., & Stewart, R. (2017). Contributions of specific causes of death to lost life expectancy in severe mental illness. *European Psychiatry*, 43, 109–115. <https://doi.org/10.1016/j.eurpsy.2017.02.487>
- Laursen, T. M., Wahlbeck, K., Hällgren, J., Westman, J., Ösby, U., Alinaghizadeh, H., ... Nordentoft, M. (2013). Life Expectancy and Death by Diseases of the Circulatory System in Patients with Bipolar Disorder or Schizophrenia in the Nordic Countries. *PLOS ONE*, 8(6), 4–10.
<https://doi.org/10.1371/journal.pone.0067133>
- Lehnert, T., Heider, D., Leicht, H., Heinrich, S., Corrieri, S., Lippa, M., ... König, H. H. (2011). Review: Health care utilization and costs of elderly persons with multiple chronic conditions. *Medical Care Research and Review*. <https://doi.org/10.1177/1077558711399580>
- Manu, P., Dima, L., Shulman, M., Vancampfort, D., De Hert, M., & Correll, C. U. (2015). Weight gain and obesity in schizophrenia: epidemiology, pathobiology, and management. *Acta Psychiatrica Scandinavica*. <https://doi.org/10.1111/acps.12445>
- Miller, D. D., Caroff, S. N., Davis, S. M., Rosenheck, R. A., McEvoy, J. P., Saltz, B. L., ... Lieberman, J. A. (2008). Extrapyramidal side-effects of antipsychotics in a randomised trial. *British Journal of Psychiatry*. <https://doi.org/10.1192/bjp.bp.108.050088>
- Os, J. Van, & Kapur, S. (2009). Seminar Schizophrenia. *Lancet*. [https://doi.org/10.1016/S0140-6736\(09\)60995-8](https://doi.org/10.1016/S0140-6736(09)60995-8)
- Oud, M. J. T., & Meyboom-de Jong, B. (2009). Somatic diseases in patients with schizophrenia in general practice: their prevalence and health care. *BMC Family Practice*, 10(1), 32.
<https://doi.org/10.1186/1471-2296-10-32>
- Perera, G., Broadbent, M., Callard, F., Chang, C. K., Downs, J., Dutta, R., ... Stewart, R. (2016). Cohort profile of the South London and Maudsley NHS Foundation Trust Biomedical Research Centre (SLaM BRC) Case Register: Current status and recent enhancement of an Electronic Mental Health Record-derived data resource. *BMJ Open*, 6(3). <https://doi.org/10.1136/bmjopen-2015-008721>
- Pillinger, T., Beck, K., Stubbs, B., & Howes, O. D. (2017). Cholesterol and triglyceride levels in first-episode psychosis: Systematic review and meta-analysis. *British Journal of Psychiatry*.
<https://doi.org/10.1192/bjp.bp.117.200907>
- Pirkis, J. E., Burgess, P. M., Kirk, P. K., Dodson, S., Coombs, T. J., & Williamson, M. K. (2005). A review of the psychometric properties of the Health of the Nation Outcome Scales (HoNOS) family of measures. *Health and Quality of Life Outcomes*, 3(1), 76. <https://doi.org/10.1186/1477-7525-3-76>
- Razzano, L. A., Cook, J. A., Yost, C., Jonikas, J. A., Swarbrick, M. A., Carter, T. M., & Santos, A. (2015). Factors associated with co-occurring medical conditions among adults with serious mental

- disorders. *Schizophrenia Research*, 161(2–3), 458–464.
<https://doi.org/10.1016/j.schres.2014.11.021>
- Ringen, P. A., Engh, J. a., Birkenaes, A. B., Dieset, I., & Andreassen, O. a. (2014). Increased mortality in schizophrenia due to cardiovascular disease – a non-systematic review of epidemiology, possible causes, and interventions. *Frontiers in Psychiatry*, 5(137), 1–11.
<https://doi.org/10.3389/fpsy.2014.00137>
- Ryan, A., Wallace, E., O'Hara, P., & Smith, S. M. (2015). Multimorbidity and functional decline in community-dwelling adults: A systematic review. *Health and Quality of Life Outcomes*, 13(1).
<https://doi.org/10.1186/s12955-015-0355-9>
- Ryan, M. C. M., Collins, P., & Thakore, J. H. (2003). Impaired fasting glucose tolerance in first-episode, drug-naïve patients with schizophrenia. *American Journal of Psychiatry*.
<https://doi.org/10.1176/appi.ajp.160.2.284>
- Schäfer, I., von Leitner, E. C., Schön, G., Koller, D., Hansen, H., Kolonko, T., ... van den Bussche, H. (2010). Multimorbidity patterns in the elderly: A new approach of disease clustering identifies complex interrelations between chronic conditions. *PLoS ONE*, 5(12), e15941.
<https://doi.org/10.1371/journal.pone.0015941>
- Schoepf, D., Potluri, R., Uppal, H., Natalwala, A., Narendran, P., & Heun, R. (2012). Type-2 diabetes mellitus in schizophrenia: Increased prevalence and major risk factor of excess mortality in a naturalistic 7-year follow-up. *European Psychiatry*.
<https://doi.org/10.1016/j.eurpsy.2011.02.009>
- Smith, D. J., Langan, J., McLean, G., Guthrie, B., & Mercer, S. W. (2013). Schizophrenia is associated with excess multiple physical-health comorbidities but low levels of recorded cardiovascular disease in primary care: Cross-sectional study. *BMJ Open*, 3(4), e002808.
<https://doi.org/10.1136/bmjopen-2013-002808>
- Spiegelman, D., Hertzmark, E., & Wand, H. C. (2007). Point and interval estimates of partial population attributable risks in cohort studies: Examples and software. *Cancer Causes and Control*, 18(5), 571–579. <https://doi.org/10.1007/s10552-006-0090-y>
- Stubbs, B., Koyanagi, A., Veronese, N., Vancampfort, D., Solmi, M., Gaughran, F., ... Correll, C. U. (2016). Physical multimorbidity and psychosis: Comprehensive cross sectional analysis including 242,952 people across 48 low- and middle-income countries. *BMC Medicine*, 14(1), 189.
<https://doi.org/10.1186/s12916-016-0734-z>
- Stubbs, B., Mueller, C., Gaughran, F., Lally, J., Vancampfort, D., Lamb, S. E., ... Perera, G. (2018). Predictors of falls and fractures leading to hospitalization in people with schizophrenia spectrum disorder: A large representative cohort study. *Schizophrenia Research*.
<https://doi.org/10.1016/j.schres.2018.05.010>
- Stubbs, B., Vancampfort, D., Hallgren, M., Firth, J., Veronese, N., Solmi, M., ... Kahl, K. G. (2018). EPA guidance on physical activity as a treatment for severe mental illness: a meta-review of the evidence and Position Statement from the European Psychiatric Association (EPA), supported by the International Organization of Physical Therapists in Mental. *European Psychiatry*, 54, 124–144. <https://doi.org/10.1016/j.eurpsy.2018.07.004>
- Tandon, R., Keshavan, M. S., & Nasrallah, H. A. (2008). Schizophrenia, “Just the Facts” What we know in 2008. 2. Epidemiology and etiology. *Schizophrenia Research*, 102(1–3), 1–18.
<https://doi.org/10.1016/j.schres.2008.04.011>
- Vancampfort, D., Correll, C. U., Galling, B., Probst, M., De Hert, M., Ward, P. B., ... Stubbs, B. (2016). Diabetes mellitus in people with schizophrenia, bipolar disorder and major depressive disorder: a systematic review and large scale meta-analysis. *World Psychiatry : Official Journal of the World Psychiatric Association (WPA)*, 15(2), 166–174. <https://doi.org/10.1002/wps.20309>
- Vancampfort, D., Firth, J., Schuch, F. B., Rosenbaum, S., Mugisha, J., Hallgren, M., ... Stubbs, B. (2017). Sedentary behavior and physical activity levels in people with schizophrenia, bipolar disorder and major depressive disorder: a global systematic review and meta-analysis. *World Psychiatry*, 16(3), 308–315. <https://doi.org/10.1002/wps.20458>

- Vancampfort, D., Koyanagi, A., Ward, P. B., Rosenbaum, S., Schuch, F. B., Mugisha, J., ... Stubbs, B. (2017). Chronic physical conditions, multimorbidity and physical activity across 46 low- and middle-income countries. *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), 6. <https://doi.org/10.1186/s12966-017-0463-5>
- Violan, C., Foguet-Boreu, Q., Flores-Mateo, G., Salisbury, C., Blom, J., Freitag, M., ... Valderas, J. M. (2014). Prevalence, determinants and patterns of multimorbidity in primary care: A systematic review of observational studies. *PLoS ONE*, 9(7), e102149. <https://doi.org/10.1371/journal.pone.0102149>
- Walker, E. R., McGee, R. E., & Druss, B. G. (2015). Mortality in Mental Disorders and Global Disease Burden Implications. *JAMA Psychiatry*, 72(4), 334. <https://doi.org/10.1001/jamapsychiatry.2014.2502>
- Winterer, G. (2010). Why do patients with schizophrenia smoke? *Current Opinion in Psychiatry*. <https://doi.org/10.1097/YCO.0b013e3283366643>
- World Health Organisation. (2016). ICD-10 Version:2016. <https://doi.org/10.1177/1071100715600286>
- Wu, H., Toti, G., Morley, K. I., Ibrahim, Z. M., Folarin, A., Jackson, R., ... Dobson, R. J. (2018). SemEHR: A general-purpose semantic search system to surface semantic data from clinical notes for tailored care, trial recruitment, and clinical research*. *Journal of the American Medical Informatics Association*. <https://doi.org/10.1093/jamia/ocx160>
- Yanbaeva, D. G., Dentener, M. A., Creutzberg, E. C., Wesseling, G., & Wouters, E. F. M. (2007). Systemic effects of smoking. *Chest*. <https://doi.org/10.1378/chest.06-2179>

Table 1. Baseline characteristics and their association to death in people with SSD.

Schizophrenia Spectrum Disorders, N=9775		
Variables	n (%)	Adjusted HR (95% CI)*
Age, n (%)		
18-39	3707 (37.9)	Reference
40-59	4377 (44.8)	2.59 (2.06-3.25)
≥60	1691 (17.3)	13.37 (10.73-16.65)
Gender, n (%)		
Females	3983 (40.7)	Reference
Males	5792 (59.3)	1.37 (1.20-1.58)
Marital status, n (%)		
Married/cohabiting	1096 (11.2)	Reference
Divorced/widowed	1267 (13.0)	1.14 (0.90-1.44)
Single	7293 (74.6)	1.14 (0.92-1.41)
Unknown	119 (1.2)	0.69 (0.28-1.69)
Ethnicity, n (%)		
White	3990 (40.8)	Reference
Black African/Caribbean	4339 (44.4)	0.73 (0.63-0.85)
Other/unknown	1445 (14.8)	0.84 (0.68-1.04)
Social deprivation index (quintiles), n (%)		
1 (Least deprived)	1957 (20.0)	Reference
2	1953 (20.0)	0.90 (0.73-1.11)
3	1979 (20.3)	0.91 (0.74-1.13)
4	1939 (19.8)	1.06 (0.86-1.30)
5 (Most deprived)	1947 (19.9)	1.06 (0.86-1.30)
HoNOS domain score		
Agitated/aggressive behaviour, n (%)		
0	7356 (75.2)	Reference
1	1327 (13.6)	1.02 (0.81-1.28)
2-4	1073 (11.0)	1.29 (1.02-1.62)
Missing	19 (0.2)	
Self-injury, n (%)		
0	9145 (93.6)	Reference
1	373 (3.8)	1.21 (0.82-1.78)
2-4	236 (2.4)	1.60 (1.02-2.49)
Missing	21 (0.2)	
Substance abuse, n (%)		
0	8012 (82.0)	Reference
1	634 (6.5)	1.18 (0.86-1.62)
2-4	1078 (11.0)	1.56 (1.22-1.98)
Missing	51 (0.5)	
Cognitive problems, n (%)		
0	7151 (73.2)	Reference
1	1488 (15.2)	1.10 (0.90-1.34)
2-4	1115 (11.4)	1.09 (0.87-1.35)
Missing	21 (0.2)	
Depression, n (%)		
0	6434 (65.8)	Reference
1	1980 (20.3)	1.16 (0.96-1.40)
2-4	1333 (13.6)	1.09 (0.86-1.38)
Missing	28 (0.3)	
Number of physical disease systems affected, n (%)		
0	1798 (18.4)	Reference
1	1715 (17.5)	1.26 (0.99-1.62)
2	1639 (16.8)	1.30 (1.02-1.66)
3	1403 (14.4)	1.34 (1.04-1.72)
4	1185 (12.1)	1.41 (1.09-1.83)
5	846 (8.7)	1.62 (1.23-2.13)
6+	1189 (12.2)	1.43 (1.11-1.85)
Disease systems affected, n (%)		

No disorder	1798 (18.4)	Reference
Viral infection	3758 (38.5)	1.38 (1.11-1.71)
Endocrine	4141 (42.4)	1.30 (1.06-1.61)
Neurologic	4859 (49.7)	1.33 (1.08-1.64)
Cardiovascular	2621 (26.8)	1.47 (1.19-1.83)
Respiratory	3609 (36.9)	1.70 (1.38-2.10)
Digestive	1822 (18.6)	1.53 (1.22-1.93)
Skin	2144 (21.9)	1.44 (1.15-1.80)
Musculoskeletal	2447 (25.0)	1.27 (1.01-1.59)
Urogenital	711 (7.3)	1.77 (1.35-2.32)

*Adjusted for age and gender

Figure 1. Prevalence rates of two-way disease system combinations presented as percentages.

	Neurologic	Endocrine	Viral infection	Respiratory	Cardiovascular	Musculoskeletal	Skin	Digestive	Urogenital
<5%									
5-9%									
≥10%									
Neurologic	N/A								
Endocrine	27.9	N/A							
Viral infection	24.9	21.4	N/A						
Respiratory	25.2	21.1	21.6	N/A					
Cardiovascular	19.9	16.8	14.6	15.0	N/A				
Musculoskeletal	17.0	15.1	13.2	15.0	10.4	N/A			
Skin	15.4	13.5	13.2	12.8	9.6	9.4	N/A		
Digestive	13.8	11.0	10.7	10.7	8.1	8.0	7.4	N/A	
Urogenital	5.4	5.0	4.1	4.2	3.6	3.2	3.0	2.3	N/A

Table 2. Cox proportional hazards regression of physical disease combinations and their association to

Physical disease combinations	Crude HR (95% CI)	Adjusted HR (95% CI)*	Adjusted HR (95% CI)†	p
No physical disease	1.0 (Ref.)	1.0 (Ref.)	1.0 (Ref.)	
Viral infection only	1.11 (0.67-1.82)	1.31 (0.80-2.17)	N/A	ns
Viral infection + Endocrine	1.39 (1.10-1.76)	1.33 (1.05-1.69)	1.19 (0.79-1.77)	ns
Viral infection + Neurologic	1.37 (1.08-1.72)	1.34 (1.06-1.69)	0.92 (0.62-1.37)	ns
Viral infection + Cardiovascular	1.75 (1.37-2.23)	1.44 (1.13-1.84)	1.06 (0.64-1.77)	ns
Viral infection + Respiratory	1.74 (1.38-2.18)	1.64 (1.31-2.06)	1.65 (1.17-2.33)	<0.01
Viral infection + Digestive	1.84 (1.42-2.38)	1.59 (1.23-2.07)	1.08 (0.61-1.90)	ns
Viral infection + Skin	1.57 (1.22-2.03)	1.35 (1.04-1.74)	0.96 (0.57-1.63)	ns
Viral infection + Musculoskeletal	1.55 (1.20-1.99)	1.39 (1.08-1.79)	1.06 (0.64-1.77)	ns
Viral infection + Urogenital	2.00 (1.42-2.80)	1.65 (1.18-2.32)	0.75 (0.26-2.18)	ns
Endocrine only	1.50 (1.01-2.22)	1.23 (0.83-1.82)	N/A	ns
Endocrine + Neurologic	1.34 (1.07-1.69)	1.23 (0.98-1.54)	0.80 (0.56-1.14)	ns
Endocrine + Cardiovascular	1.69 (1.33-2.15)	1.29 (1.01-1.64)	0.83 (0.52-1.30)	ns
Endocrine + Respiratory	1.72 (1.37-2.16)	1.62 (1.29-2.04)	1.72 (1.18-2.49)	<0.01
Endocrine + Digestive	1.58 (1.21-2.07)	1.42 (1.09-1.86)	1.11 (0.63-1.94)	ns
Endocrine + Skin	1.63 (1.26-2.09)	1.41 (1.09-1.82)	1.51 (0.95-2.42)	ns
Endocrine + Musculoskeletal	1.39 (1.08-1.79)	1.21 (0.93-1.56)	0.94 (0.59-1.50)	ns
Endocrine + Urogenital	2.09 (1.53-2.86)	1.66 (1.22-2.28)	0.80 (0.36-1.75)	ns
Neurologic only	1.09 (0.73-1.63)	1.20 (0.80-1.79)	N/A	ns
Neurologic + Cardiovascular	1.85 (1.47-2.33)	1.46 (1.16-1.83)	1.22 (0.84-1.77)	ns
Neurologic + Respiratory	1.86 (1.49-2.32)	1.71 (1.38-2.14)	1.84 (1.35-2.52)	<0.001
Neurologic + Digestive	1.78 (1.39-2.28)	1.58 (1.24-2.03)	1.19 (0.76-1.87)	ns
Neurologic + Skin	1.73 (1.36-2.20)	1.46 (1.15-1.86)	1.31 (0.83-2.05)	ns
Neurologic + Musculoskeletal	1.45 (1.14-1.86)	1.29 (1.01-1.66)	0.67 (0.41-1.10)	ns
Neurologic + Urogenital	2.25 (1.68-3.03)	1.83 (1.36-2.46)	1.08 (0.52-2.31)	ns
Cardiovascular only	3.04 (1.92-4.81)	1.97 (1.24-3.12)	N/A	
Cardiovascular + Respiratory	2.34 (1.86-2.95)	1.78 (1.41-2.25)	2.23 (1.49-3.32)	<0.001
Cardiovascular + Digestive	1.93 (1.47-2.54)	1.51 (1.15-2.00)	1.33 (0.65-2.71)	ns
Cardiovascular + Skin	2.00 (1.54-2.60)	1.46 (1.13-1.90)	1.07 (0.57-2.00)	ns
Cardiovascular + Musculoskeletal	1.72 (1.32-2.25)	1.30 (0.99-1.69)	0.71 (0.37-1.37)	ns
Cardiovascular + Urogenital	2.64 (1.92-3.65)	1.81 (1.31-2.50)	0.71 (0.26-1.93)	ns
Respiratory only	1.16 (0.67-2.03)	1.12 (0.64-1.95)	N/A	ns
Respiratory + Digestive	2.23 (1.74-2.86)	1.88 (1.47-2.41)	1.88 (1.14-3.11)	<0.05
Respiratory + Skin	2.04 (1.60-2.60)	1.75 (1.37-2.24)	2.06 (1.31-3.24)	<0.01
Respiratory + Musculoskeletal	1.88 (1.47-2.40)	1.62 (1.27-2.07)	1.57 (1.01-2.44)	<0.05
Respiratory + Urogenital	2.73 (2.02-3.70)	2.00 (1.48-2.72)	1.39 (0.65-2.96)	ns
Digestive only	1.34 (0.59-3.06)	1.13 (0.49-2.58)	N/A	ns
Digestive + Skin	1.92 (1.45-2.55)	1.59 (1.20-2.12)	0.96 (0.44-2.08)	ns
Digestive + Musculoskeletal	1.80 (1.36-2.38)	1.54 (1.16-2.04)	0.71 (0.33-1.54)	ns
Digestive + Urogenital	2.65 (1.82-3.86)	2.07 (1.42-3.02)	1.97 (0.63-6.15)	ns
Skin only	1.35 (0.66-2.77)	1.03 (0.50-2.12)	N/A	ns
Skin + Musculoskeletal	1.75 (1.33-2.29)	1.41 (1.07-1.85)	0.68 (0.35-1.31)	ns
Skin + Urogenital	2.70 (1.92-3.79)	2.05 (1.45-2.88)	1.39 (0.45-4.28)	ns
Musculoskeletal only	0.9 (0.42-1.94)	0.88 (0.41-1.88)	N/A	ns
Musculoskeletal + Urogenital	2.42 (1.71-3.41)	1.85 (1.31-2.61)	0.70 (0.25-1.97)	ns
Urogenital only	3.68 (1.50-9.02)	1.87 (0.76-4.61)	N/A	ns

death.

* Adjusted for age and gender

† Adjusted for age, gender, and all other physical disease systems (chapter B-N)

N/A, not applicable

Significance testing for the final adjusted model only (†)

Table 3. Top five highest population attributable fractions (PAFs) for 5-year mortality associated with physical multimorbidity combinations as well as single diseases in patients with SSD

Physical disease combinations and single diseases ranked by PAF	PAF estimate (%; 95%CI)	p
No physical disease	Ref.	Ref.
Physical multimorbidity		
Cardiovascular + Respiratory	35.7 (23.0-46.3)	<0.001
Neurologic + Respiratory	32.7 (19.3-43.8)	<0.001
Respiratory + Skin	29.8 (15.8-41.5)	<0.001
Endocrine + Respiratory	27.5 (11.7-40.5)	<0.001
Respiratory + Digestive	26.4 (9.4-40.3)	<0.001
Single diseases		
Cardiovascular alone	8.1 (4.2-9.6)	<0.001
Neurologic alone	3.6 (-3.9-10.6)	ns
Endocrine alone	4.2 (-3.2-11.1)	ns
Respiratory alone	1.2 (-4.6-6.6)	ns
Skin alone	0.2 (-4.5-4.8)	ns
Digestive alone	0.6 (-3.3-4.3)	ns

PAF calculated by an adjusted cox regression analysis adjusted for age, gender, and all other physical disease systems.

Abbreviations: PAF, population attributable fraction



22 June 2019

Reviewer #1

Well written overall. Minor grammar corrections. However, the substantial amount of work that has gone on in writing the article has given results (and the message) the magnitude of which can be accommodated into a brief report. Authors may consider this.

Response

Thank you for your positive feedback and also the suggestion to improve the grammar within our manuscript. The manuscript will be corrected by our proofreader from our research department before resubmitting. We appreciate the suggestion to consider the study as a brief report, however, we still believe that this study fulfills the requirement for an “original investigation”. However, if the editor decides this manuscript to be a brief report, we would of course accept this decision, and make the necessary changes.

Reviewer #2

The authors have used a population based study to study the effects of somatic co-morbidity/multi-morbidity in addition to Schizophrenia. Time to death and 5-year mortality are the main outcomes of investigation. Though the research motive is clear and very relevant for reducing morbidity and mortality outcomes, this investigation is not enough advance or of enough impact for the journal. My biggest critique is that no smoking data or alcohol usage is used as predictors in the model. The authors should at least acknowledge this in their limitations as they are strong confounds especially in the said population. The results table in a way allude to this limitation, with respiratory system being a strong contributor for morbidity outcomes.

Response

Thank you for this very valid comment. We highly appreciate your concern regarding lack of information on smoking and alcohol, which we agree are important variables for mortality, especially in this specific study population. However, we were not able to include such variables in our data extraction. We agree that this should be discussed in the limitation section of the paper, which we apologize for not having included in the initial draft, thus we have now corrected the limitation section to include a more comprehensive discussion of the contribution of these confounders to our study findings.

Revision: Added to the limitation section

“It is a major limitation that the current data did not include information on important confounders, such as smoking and alcohol consumption as well as levels of physical activity and intake of healthy diet, which are important variables in morbidity and mortality outcomes. For example, the finding that respiratory system is a strong contributor for morbidity and mortality in patients with SSD could be confounded by the excessive rates of smokers in patients with SSD, and we would have expected to reduce some of the respiratory mortality if we were able to include smoking as a variable in our regression model. On the other hand, smoking cessation is very difficult to implement in patients with



SSD, and some patients even use smoking as self-medication to handle negative and cognitive symptoms (PEF) which again challenges the use of such adjustment in our analysis.”

22 June 2019

Reviewer #3

This manuscript provides a population approach to understanding the association between physical multi morbidity and mortality in schizophrenia spectrum disorders. The study method uses computer programs to record physical morbidity from a large database. Results are in keeping with current understanding and the novelty of findings is rather limited. Important confounding elements are not strictly covered for, partly due to the limited inherent properties of the data collecting process. Here are my specific comments:

Response

We are pleased that reviewer #3 acknowledges the importance of our work and offers additional input to help improve our manuscript. We are unaware of any previous representative cohort studies that have specifically investigated physical multimorbidity patterns and mortality in schizophrenia and believe the paper fills an important gap in the literature. In fact, this is a gap, which we have identified in our forthcoming (released July 22nd) Lancet Commission to improve the physical health of people with mental disorders.

Reviewer #3 #1

Introduction: The clinical relevance of this area needs to be supplemented with the novelty that this particular investigation adds to the available literature. The authors state "little is known about the prevalence and impact of physical health multimorbidity"; however, they also quote a range of studies indicating "a higher risk of physical health multimorbidity (in schizophrenia) compared to the general population". The specifics of the "improved evidence base" this article can provide is also wanting.

Response:

Thank you very much for highlighting this inconsistency in our introduction as well as the lack of description regarding the novelty of our study. We agree that some of the sentences should be revised in our introduction, and therefore the following revisions have been made in the manuscript:

Revision:

Before: *“Whilst there have been concerted efforts to understand poor physical health in schizophrenia, little is known about the prevalence and impact of physical health multimorbidity.”*

Now: *“Whilst there have been concerted efforts to understand poor physical health in schizophrenia, little is known about the impact of physical health multimorbidity on mortality in these patients.”*

22 June 2019

The following has been added in the introduction:

“The study by Gabilondo et al. (2017) showed that physical disease clusters of neuropsychiatric conditions (Parkinson, dyspepsia, cerebrovascular disease) as well as cardiovascular and respiratory disease clusters were most common. Stubbs et al. (2016) reported that psychosis patients had high levels of asthma combined with diabetes, angina pectoris or tuberculosis, and arthritis combined with angina pectoris, and hearing problems combined with visual impairment or edentulism. Even though such combinations show that physical morbidities co-occur frequently in patients with SSD, no studies have to date investigated the impact of such combinations to mortality, which is necessary in order to understand and possibly reduce the premature mortality in patients with SSD.”

Reviewer #3 #2

Method: Identification of physical multi morbidity is solely dependent on the accuracy of the computer program used to parse through clinical notes. This is a major advancement, yet a limitation - as it is not a gold standard method of ascertaining morbidity. Hence, this needs to be highlighted in the title and abstract of the manuscript. If these programs have been used in any manuscripts other than Wu et al., 2018 - those may be quoted. When the authors say "The precision at chapter level after removing poor-performing chapters is $86\% \pm 0.11$." - what is the source of data and confirmation method for estimating precision? Also, can you provide examples of physical disorders coded under each system - neurological, endocrine, respiratory, skin, etc.?

Response:

Thank you again for your suggestion. We agree that the title and abstract should reflect the methodology used in our study, thus the following revision has been made in the title:

Before: *“Physical health multimorbidity and its association to mortality rates in people with schizophrenia spectrum disorders: a retrospective cohort study”*

Now: *“Association of physical health multimorbidity with mortality in people with schizophrenia spectrum disorders: Using a novel semantic search system that captures physical diseases in electronic patient records”*

The following correction has been made in the abstract:

Before: *“A retrospective cohort study between 2013 and 2017. All people with a diagnosis of SSD (ICD-10: F20-F29), who had contact with secondary mental healthcare within South London during 2011-2012 were included. Physical health conditions were ascertained from electronic mental health records and all-cause mortality from a national registry. Hazard ratios (HRs) and population attributable fractions (PAFs) were calculated for associations between physical multimorbidity and all-cause mortality.”*

Now: *“A retrospective cohort study between 2013 and 2017. All people with a diagnosis of SSD (ICD-10: F20-F29), who had contact with secondary mental healthcare within South London during 2011-2012 were included. We used a novel semantic search system to capture physical health conditions from electronic mental health records, and all-cause mortality were retrieved from a national registry. Hazard ratios (HRs) and population attributable fractions (PAFs) were calculated for associations between physical multimorbidity and all-cause mortality.”*

The computer program (SemEHR) has been recently used and validated against other machine learning tools on Radiology Reports in Scotland. It is described in the following reference (quoted in the manuscript).

“Gorinski, Philip John, Honghan Wu, Claire Grover, Richard Tobin, Conn Talbot, Heather Whalley, Cathie Sudlow, William Whiteley, and Beatrice Alex. "Named Entity Recognition for Electronic Health Records: A Comparison of Rule-based and Machine Learning Approaches." Accepted by the second UK healthcare text analytics conference – HealTAC 2019; arXiv preprint arXiv:1903.03985 (2019).”

Revision: p. 9 (additional lines added)

“The SemEHR has been recently used and validated against other machine learning tools on Radiology Reports in Scotland (Gorinski et al., 2019).”

Regarding the precision of poor performing chapters (what is the source of data and confirmation method for estimating precision?). The source of (validation) data was generated in the study by two annotators (P.K. and R.S.) via 16 rounds of iterations. The precision at chapter-level was estimated by manual assessments on sampled documents (80 documents per chapter of the last rounds).

Revision: p. 9

Before: *“The precision at chapter level after removing poor-performing chapters is $86\% \pm 0.11$.”*

Now: *“The precision at chapter level after removing poor-performing chapters is $86\% \pm 0.11$. The source of (validation) data was generated in the study by two annotators (P.K. and R.S.) via 16 rounds of iterations. The precision at chapter-level was estimated by manual assessments on sampled documents (80 documents per chapter of the last rounds).”*

The suggestion to include specific physical disease examples within each physical main category is much appreciated, and we have now corrected the description of these categories in the methods by including few examples (the most common) within each category:

Before: *“These were therefore not included in the multimorbidity algorithm used for analyses described here, which instead ascertained viral infection (chapter B), endocrine (chapter E), neurologic (chapter G), cardiovascular (chapter I), respiratory (chapter J), digestive (chapter K), skin (chapter L), musculoskeletal (chapter M) and urogenital (chapter N) systems.”*

Now: *“These were therefore not included in the multimorbidity algorithm used for analyses described here, which instead ascertained viral infection (chapter B, e.g. HIV, mycoses, hepatitis.), endocrine (chapter E, e.g. diabetes mellitus, cystic fibrosis, obesity), neurologic (chapter G, e.g. Parkinson disease, epilepsy, Huntington disease), cardiovascular (chapter I, e.g. stroke, heart failure, myocardial infarction), respiratory (chapter J, e.g. asthma, bronchitis, chronic obstructive pulmonary disease), digestive (chapter K, e.g. liver diseases, gastric ulcer, irritable bowel syndrome), skin (chapter L, e.g. psoriasis, eczema, dermatitis), musculoskeletal (chapter M, e.g. systemic lupus,*

22 June 2019

arthrosis, dorsopathies) and urogenital (chapter N, e.g. renal failure, endometriosis, diseases of genital (male/female) organs) systems.”

Reviewer #3 #3

Outcomes: Was there any information on causes of mortality that could have been available from the database accessed by the investigators? Was suicide as a cause for mortality excluded? Similarly, what steps were taken to ensure that the mortality was not related to the physical multi morbidity to prevent inferences of false / confounding associations?

Response:

Thank you for this comment. It is not possible to extract causes of death from the clinical database (CRIS) used, as we were only able to access status and time of death. This type of information would only have been possible to retrieve from the Office of National Statistics (ONS), which we unfortunately did not have access to. Therefore, our sample included all deaths (also suicide and other unnatural deaths), which of course challenges the interpretation of our findings. However, we agree that suicide contribute to the excess mortality in patients with schizophrenia spectrum disorders, perhaps even conflicting the outcomes observed in the group of people with zero somatic diseases, as our results showed no significant differences between one and zero somatic diseases. We believe that the high risk of suicide mortality in people with SSD conflicts the current study design due to the problem regarding the competing risk phenomenon, as a majority of these patients might die early preventing people from developing somatic disease. We appreciate this concern, and we have added some sentences in the limitation section to elucidate this problem.

Revision: p. 17. Added to the limitation section

“The increased risk of suicide mortality in these patients challenges the findings observed in the current study, as many patients die early without having the chance to develop somatic diseases (competing risk). This is often considered as a major limitation in observations studies.”

Reviewer #3 #4

Covariates: The authors use data from the Health of the Nation Outcome Scales (HoNOS). Please provide details of how (structured interview, clinical consult notes, etc) this information is recorded and who (trained raters, experts, GPS) rates these and how often? Also, substance abuse is an important confounder here. What steps were taken to gain adequate information about nicotine, alcohol, cannabis and other SUDs?

Response

Thank you very much for this comment. In the United Kingdom, since the mid 1990's mental health services have completed the HONOS scale among all patients. The HONOS is also widely used in Australia and New Zealand and is a validated measure with robust psychometric properties to routinely assess outcomes in mental health service users. The HONOS scale has 12 items and it has been used in over 40 papers published from the CRIS database and 290 on Pubmed as of 21/6/2019.



22 June 2019

<https://www.ncbi.nlm.nih.gov/pubmed/?term=Health+of+the+Nation+Outcome+Scales>

All mental healthcare staff receive training in completing the HONOS and this is completed by care coordinators.

Regarding your questions on smoking and SUDs. This information is not available for all patients and we have updated our limitations to state this (please see response to comment #2).

Reviewer #3 #5

Analysis: Why was physical multimorbidity categorised?

"We calculated crude and adjusted HRs and their 95% CIs by using patients with schizophrenia who had no recorded physical diseases as reference." - was this from the same dataset? Why was this restricted to schizophrenia and not schizophrenia spectrum disorders?

Response

We categorized physical multimorbidity due to the high level of patients with SSD who had 2 or more physical diseases (64.1%). When analyzing the data, it is important to level out or show the differences in cases within the specific number of diseases. If we observed the largest effect of mortality in the highest number of physical diseases, it would have been more useful to look into more disease combinations than the two disease combination that we chose to calculate. But again the results reported in table 1 showed that there was no significant difference in mortality rates from two physical diseases to six physical diseases, but a general significant effect of increased physical multimorbidity on mortality when compared to the reference group (zero physical disease).

Regarding the second concern of the statement highlighted, we apologize the written mistake that regrettably created this confusion. All analysis is based on the same data and therefore it should correctly have been "patients with schizophrenia spectrum disorders" and not just "schizophrenia". We have corrected this in our manuscript:

Revision:

"We calculated crude and adjusted HRs and their 95% CIs by using patients with SSD who had no recorded physical diseases as reference."

Sincerely,

Pirathiv Kugathasan and Brendon Stubbs on behalf of co-authors

Role of the funding source

Brendon Stubbs is supported by a Clinical Lectureship (ICA-CL-2017-03-001) jointly funded by Health Education England (HEE) and the National Institute for Health Research (NIHR). Brendon Stubbs is part funded by the NIHR Biomedical Research Centre at South London and Maudsley NHS Foundation Trust. Brendon Stubbs is also supported by the Maudsley Charity, King's College London and the NIHR South London Collaboration for Leadership in Applied Health Research and Care (CLAHRC) funding. This paper presents independent research. The views expressed in this publication are those of the authors and not necessarily those of the acknowledged institutions.

Accepted author manuscript